# Enhancing Spaceworthiness Process Based on Certification Procedures Applied in KC-390 and Gripen F-39

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***Abstract* – This work contextualizes military airworthiness certification and its importance for aerospace products. Additionally, it summarizes the military aircraft Type Certification process applied to the KC-390 and F-39 projects, listing good practices for the proposition of application in the space context. For this, the work: 1) reviews and analyzes the national and international context and identifies Sweden and Brazilian military certification processes; 2) Presents the spaceworthiness process used in Brazil; and 3) Compares processes present and validates suggestions for improvement. At the end of the work, it was possible to understand the processes and their standards and present some activities and examples of their application in spaceworthiness. In addition, the practices adopted can serve as an example for other industries and applications.**

***Keywords* – military certification, spaceworthiness, airworthiness.**

## I. INTRODUCTION

On October 23, 1906, Brazilian aviator Alberto Santos-Dumont achieved a significant milestone in aviation history. With his aircraft, the 14-Bis, Santos-Dumont successfully performed a manned and controllable flight, demonstrating maneuverability in all three axes. He flew for approximately 60 meters at about 5 meters [1]. This accomplishment was noteworthy as the aircraft relied on its propulsion system, setting it apart from other attempts to create airplanes. Santos-Dumont's feat took place in front of a large audience, including the Official Commission of the Aero Club of France, a respected international institution responsible for approving such achievements [2].

About forty years later, during World War II, the impact of aerial warfare highlighted the significance of aircraft in military operations. This realization led to an unprecedented scale of aircraft production. Despite the challenges faced during the wartime period, aviation technologies advanced, benefiting from the demands of the conflict.

While Europe dealt with bombings and conflicts, commercial aviation experienced significant growth in the Americas. A robust passenger and cargo transportation network was established, demonstrating excellent expansion potential [3]. However, technical and political obstacles threatened the growth of this emerging economic sector. In response, the United States organized a major international conference on civil aviation in 1944, known as the Chicago Convention [4].

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This conference aimed to establish a global framework for mutual recognition and harmonizing safety requirements in commercial aviation. The outcome was the creation of the International Civil Aviation Organization (ICAO), headquartered in Montreal, Canada.

The primary objective of the ICAO has been to promote uniformity among states in the regulations, standards, procedures, and organizational practices of civil aviation [5]. The ICAO has facilitated safe and efficient air travel worldwide through international cooperation and standardization efforts. Today, passengers can embark on flights operated by airlines from different countries, flying on aircraft manufactured elsewhere while enjoying consistent safety standards.

Aircraft certification activities significantly contribute to the safety of civil aviation operations. The main goal of airworthiness requirements is to prevent recurring accidents due to design flaws [6]. By establishing rigorous standards and conducting meticulous assessments, certification authorities ensure that aircraft meet the necessary safety criteria before being authorized for operation.

Over time, space exploration has involved geopolitically significant governments and private organizations. Initially, space achievement required significant investment and extensive engineering efforts. As the technologies involved became more accessible and the necessary knowledge disseminated, private companies started getting involved in the space industry [7].

Currently, we are witnessing the beginning of commercial space utilization by private companies, which are already capable of launching multiple satellites simultaneously, reusing launch vehicles, and pioneering initiatives in space tourism and passenger transportation. This intense involvement of the private sector in the space industry is evident. According to [8], approximately 179,000 professionals work in the American space sector, with 135,000 employed by private companies. In contrast, NASA employs only about 17,000 individuals. Similar to the early days of the aviation industry, this recent participation of the private sector in space operations will need to be heavily regulated to enable global spaceflight and ensure the safety of civilian passengers. Establishing the ICAO, signing the Chicago Convention in 1944, and harmonizing certification and operational requirements were instrumental in making civil aviation a viable business [9].

The significance of aerospace certification goes beyond its contributions to the aviation industry. Its primary value lies in enhancing operational safety and preserving human lives. Certification activities ensure continuous improvement in aviation safety standards, preventing recurring accidents and rectifying design flaws. It is also important to mention that military aerospace certification encompasses additional considerations, such as mission fulfillment. Military certification authorities adopt processes that guarantee airworthiness, considering specific objectives. When considering a scenario for applying the spaceworthiness concept, valuable lessons can be learned from renowned military aerospace certification processes, such as those used for the KC-390 (Brazil) and Gripen F-39 (Sweden).

This article is organized as follows: Section II presents the theoretical foundation, Section III details the research methodology employed in this study, Section IV presents the results and their applications, and finally, Section V discusses the conclusions and final considerations.

## II. THEORETICAL FOUNDATION

### *A. Certification of Military Aerospace Projects in Brazil*

To comprehend Brazil's military aerospace certification process, it is necessary to understand the concept of conformity assessment. Per reference [10], conformity assessment demonstrates that requirements for a product, process, system, person, or organization are met. The conformity assessment of a military aeronautical product can be performed by the manufacturer or supplier (first party), the operator or customer (second party), or by a certification authority that has no direct and financial interest in the product's commercialization (third party), as indicated in reference [10]. For military aeronautics, Type Certification aims to ensure that the design of a given aircraft is safe and fulfills its intended missions, as outlined in the reference. A standard certification process consists of five phases: (1) conceptual design, (2) requirement definition, (3) planning for compliance demonstration, (4) implementation, and (5) post-certification, as described in reference [10]. A unique aspect of Brazil's military certification process is that mission requirements are also certified in addition to safety requirements. This amplifies the necessity for requirements with clear writing that meet the actual needs of stakeholders since the concept of mission requirements requires a framework of requirements as well established as safety requirements.

The military certification authority in Brazil is the Industrial Fostering and Coordination Institute (IFI), subordinated to the Department of Aerospace Science and Technology (DCTA). IFI published the Brazilian Air Force Instruction (ICA) No. 57-21, titled “Airworthiness Regulation Military - Procedures for Aeronautical Product Certification," for its process. This document defines, among other topics, the process and rules of airworthiness certification.

With the process covered, the certification basis is defined based on civilian airworthiness and contractual requirements, following the criteria in MIL-HDBK-516. This handbook brings the criteria that a military aircraft's systems should fulfill to ensure that it is airworthy [17]. The KC-390 is a successful example of this certification strategy; this military aircraft is the largest developed, manufactured, and in the process of military certification in the Southern Hemisphere. It showcases a versatile range of capabilities, including Logistic Air Transportation, Refueling in Flight (REVO), Aeromedical Evacuation, Search and Rescue, Combat Fire in Flight, and, notably, the proficient launch and support of paratroopers in airborne operations, among others.

### *B. Military Airworthiness Certification in Europe*

The European Defense Agency, EDA, aims to develop capabilities and military cooperation between the European Union Member States to enhance their defense capabilities and technological development [11].

Having acted for the land, sea, and air, it is possible to highlight the publication of EMAR 21 (European Military Airworthiness Requirements) for the airworthiness discussion.

This document follows a similar structure to the already established part 21 from European Aviation Security Agency (EASA). It is defined as the main requirements that the military airworthiness certification process should fulfill.

One important high point is that the EDA is an agency, not the airworthiness authority as EASA. European countries can take the EMAR 21 as a guideline for establishing their certification process.

### *C. Military Airworthiness Certification Projects in Sweden*

The Swedish military certification authority SE-MAA (Swedish Military Airworthiness Authority) established the SE-EMAR 21 as the guideline of the airworthiness certification process.

The SE-EMAR 21 (Swedish European Military Airworthiness Requirements) is the document that institutes the requirements that should be fulfilled by the organizations that provide airworthiness services. This document is a tailoring of the EMAR 21 added for some Swedish requirements [12].

Although the SE-EMAR 21 give some guideline, the document does not define a certification basis. The MIL-HDBK-516 is used as a guideline for constructing their certification basis. The most notorious project from this authority is the F-39 Gripen, which follows a similar process as the one adopted in Brazil.

### *D. Relevance of Studying Military Certification Practices for Space Product Assurance*

The Brazilian military aircraft certification process aims to ensure safety and mission compliance. This safety concern is also central to the space product assurance process. Therefore, studying the practices and criteria adopted in Brazilian military certification is relevant for enhancing space product assurance activities.

In order to promote convergence between aerospace and space processes, the Brazilian Space Agency (AEB) issued a Directive authorizing the IFI to act as a Space Certification Body [13].

Considering the future certification in the space domain, it would be pertinent to align satellite product assurance activities with certification activities. This could result in more stringent requirements, improved activities, and better control over aerospace and space processes.

Specifically, concerning the "Spaceworthiness" theme, IFI published the ICA No. 60-2, titled "Procedure for Certification of Product and Quality Management System in the Space Sector." This instruction applies to acquisition/development contracts with private companies or government entities, in which DCTA is responsible for management and operation, and developments carried out by DCTA itself. Moreover, it aims to fulfill the objectives established by the Brazilian Space Agency in appointing IFI as a space certification body [14].

Within the context of AEB, the Brazilian Space Regulation (REB) Part 02, titled "Launch Authorization," dated August 31, 2021, features Annex C, which addresses safety-related topics [15]. This annex covers several crucial aspects to ensure safety during space operations.

## III. METHODOLOGY

This section describes the methodological steps adopted to achieve the objective of this study. The following steps will be performed:

**Step 1**: Presentation of the aeronautical, military-type certification process used in Sweden and Brazil: In this step, the stages of the process will be identified, and good practices of the process under investigation will be highlighted.

**Step 2**: Presentation of the space type certification process in Brazil: In this step, the process phases will be identified, and some challenges under investigation will be highlighted.

**Step 3**: Comparison and analysis based on the authors' experience: In this step, the authors will use their experience and knowledge to compare and analyze the processes to identify potential Proposals of improvement in the spaceworthiness process.

**Step 4**: Validation of information through presentation and questionnaire with aerospace industry experts: To validate the findings from Step 3, information will be presented to aerospace industry experts. Subsequently, a structured questionnaire will be applied to collect feedback and validate the information obtained based on the experience of these specialists.

These methodological steps were defined to achieve the objective of this study, ensuring the collection of relevant data and validation of the conclusions obtained.

## IV. RESULTS AND APPLICATIONS

This section lists the aircraft/spacecraft type certification process directly related to its airworthiness/spaceworthiness, as it ensures that the aircraft/spacecraft meets the safety and performance requirements necessary for safe operation. During type certification, the aircraft/spacecraft undergoes rigorous testing, inspections, and evaluations to ensure compliance with established regulatory standards.

Certification requirements cover various aspects of the aircraft/spacecraft, including design, materials, systems, structures, operation, and maintenance procedures. Through this process, regulatory authorities verify that the aircraft/spacecraft is designed and built to meet safety standards, ensuring its ability to operate safely under various operating conditions. Obtaining type certification legally considers the aircraft/spacecraft fit to fly and, therefore, airworthy/spaceworthy. This process is essential to ensure the safety of passengers, crew, and others involved in operations, inspiring operators and regulatory authorities with confidence that the aircraft/spacecraft meets the highest safety and quality standards.

### *A. Aeronautical, military-type certification process*

Fig. 1. Shows the phases of the aeronautical, military-type certification process used in Sweden and Brazil and highlights some practices performed in each phase.

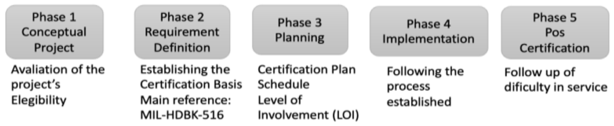


Fig. 1.
Phases of the aeronautical, military-type certification process.

The certification process is initiated in the Conceptual Project (Phase 1), during which the authority evaluates the project's Eligibility. One of the approaches to carrying out the aeronautical certification process is through accreditation by the Applicant Company, known in Brazil as Accredited Design Organization (OPC), following, as far as possible and appropriate, the model used by EASA, which is described in Regulation Part 21 - Subpart J - DOA (Design Organization Approval). Among the several advantages of this approach, the speed in the execution of the other phases stands out since the applicant acts directly as an essential tool in demonstrating the requirements.

In Requirements Definition (Phase 2), the certification authority refines and agrees on the requirements applicable to a design or modification, known as the Certification Base, in collaboration with the developer [10–16, 20]. A handy tool for global certification is the use of MIL-HDBK-516. This manual brings the criteria that the systems of a military aircraft must meet to ensure its airworthiness [17].

In the compliance planning phase (Phase 3) demonstration, the certification authority assesses its involvement in certification activities based on the risk factors and consolidation plans initiated in the previous phase [10–16, 20].

The level of involvement will be more significant as one or more assumptions are impacted, namely:

• Developer understanding of Requirements and Methodologies applicable to the project

• Company experience with the project to be certified

• Security and Criticality of the requirement

To define the level of involvement within the context of the military-type certification process, ICAs 57-22 and 57-23 are used [18, 19].

During the implementation phase (Phase 4), the certification plan's agreed-upon activities are executed, such as laboratory or flight tests, compliance inspections, and analyses. After the conformity evaluation is satisfactorily completed, the certifying authority may issue the Type Certificate (TC) [10–16, 20]. The TC has the same function as a diploma, attesting to compliance with the Certification Basis requirements. Equally important is the Type Certificate Data Sheet (TCDS), an attachment to the TC that specifies the project's fulfilled requirements and establishes its operational envelope, i.e., the limits considered safe for the product's use [10–16, 20].

The final phase, post-certification (Phase 5), entails finalizing the documentation to record the conducted activities and future modifications and occasionally addressing issues associated with design failures or corrections [10–16, 20].

*B. Space type certification process in Brazil*

Fig. 2. It presents the stages of the space type certification process in Brazil and highlights some practices carried out in each stage.

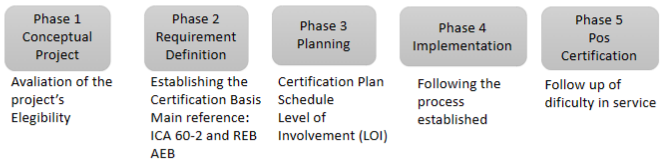


Fig. 2. Phases of the space type certification process in Brazil.

Analogously to the aeronautical process, the space process also has five phases during its certification process, and the steps are described in the ICA 60-2 included in order to complement the safety criteria established for AEB, providing guidelines and requirements for release activities [14]. This includes the system safety program, risk control strategies, flight safety analysis, risk control for safety critical hardware, other restricted risk controls, and ground safety.

To obtain safety approval and Launch Authorization, the applicant must meet the requirements specified in this section and Annex C of REB 02 [15]. The AEB issues this approval after assessing whether the applicant can launch without endangering the public health, safety, and property of uninvolved third parties.

In summary, Annex C of REB 02 covers a wide range of topics related to safety in launch operations. These measures aim to ensure that space activities are carried out safely, minimizing risks and safeguarding the health and property of all parties involved.

*C. Comparison of Processes*

The airworthiness and spaceworthiness processes will be compared based on the five phases of the type certification process. Greater focus will be given to the proposals of possible improvements in the space process to guide the proposals presented in subsection D of this section.

**PHASE 1**

To better understand the project, preliminary data covering technical requirements, operational characteristics, and limitations are required.

In this context, if the space capacity requirements for certification are considered inappropriate for a specific product due to its unique characteristics or contractual conditions, special conditions or amendments will be introduced to guarantee an equivalent level of safety.

To better clarify these "doubts," the military aeronautical certification uses the MIL-HDBK-516 [17].

The proposition of a similar manual for an application in the space context is relevant since this manual would bring the criteria that the systems of a spacecraft must meet to guarantee its spaceworthiness.

**PHASE 2**

At this stage, the applicant must present the spaceworthiness requirements related to the safe fulfillment of the mission in the form of a Certification Base, and the technical requirements established in the AEB space safety regulations (in the space case) must be included.

Defining the technical requirements for fulfilling the mission, the certificate applicant may be asked to demonstrate that the product meets the environmental protection requirements when required by contract and established by AEB regulations.

There needs to be clarity as to the level of involvement of the authority within the space context. For the aeronautical process, standardization for defining the level of involvement of the authority in the process helps in a greater understanding that the involvement will be more significant as one or more assumptions are affected, namely:

- Developer understanding of the Requirements and Methodologies applicable to the project
- Company experience with the project to be certified
- Security and criticality of the requirement

For an application in the space, specific standards must be constructed.

**PHASE 3**

In this phase, there is a direct application of the level of involvement since the certificate applicant must present a Certification Plan (PC) containing, at least the description and technical characteristics of the project, the Certification Base (requirements of spaceworthiness and fulfillment of the technical mission and environmental protection) and their respective means of attendance.

### PHASE 4

At this stage, the concept of the strategy presented is directly applied since the applicant must carry out all the necessary tests and inspections to determine: Compliance with the requirements of the Certification Base and environmental protection requirements, that the materials and products comply with the type design specifications, that the product parts comply with the type design drawings and that the manufacturing, integration, assembly, and acceptance processes are specified in the type design.

In addition, the applicant for a Type Certificate must declare that it has demonstrated Conformity with the Base Type Certification and environmental protection requirements and how such compliance has been demonstrated.

In this way, creating a certification approach similar to accreditation by the Applicant Company, such as the Accredited Design Organization (OPC) or the DOA (Design Organization Approval) model, could bring incredible speed and credibility to the execution of this phase.

### PHASE 5

The final phase, post-certification, involves completing the documentation to record the activities and future modifications. For dealings with this follow-up, there is usually an office dedicated to the follow-up of each project.

### *D. Proposals of improvement in the spaceworthiness process (Questionnaires)*

1- Would the use of a guide dedicated to space, such as MIL-HDBK-516, help to ensure that the space product's technical requirements, operational characteristics, and limitations are appropriately understood in this initial stage of the certification process?

2- Would the use of dedicated standards for the level of involvement in specific requirements help define their criticality in spaceworthiness to ensure the safe fulfillment of the space mission?

3- Would using the OPC or DOA approach be an efficient strategy to carry out the necessary tests and inspections to guarantee compliance with the certification base, ensuring that materials and products meet design specifications and that manufacturing and assembly processes comply?

4- Can create a dedicated office for monitoring the post-certification of a product guarantee a more agile and reliable execution of the tasks related to this phase?

5- In your opinion, is there any negative point in adopting airworthiness principles for the airworthiness process? (This question is free to answer and aims to collect any difficulties in implementing the proposals.)

### *E. Results and Analysis*

The criteria are evaluated using the Likert scale, which consists of a scale used for opinion research, with psychometric responses in the form of questionnaires. In this case, the scale measures agreement or disagreement with the statement. In this work, five levels of answers are used, according to Table I., for questions 1 to 5.

TABLE I. EVALUATION OF THE CRITERIA

| | ***Rating Scale*** |
|---|---|
| 1 | I disagree |
| 2 | I disagree, partially |
| 3 | Indifferent |
| 4 | Agree, partially |
| 5 | I agree |

Table 2 presents the results from the answers of the interviewees.

TABLE II. RESULTS

| | ***Evaluation notes*** |
|---|---|
| Proposals | Average |
| 1 | 4.8 |
| 2 | 4.6 |
| 3 | 4.2 |
| 4 | 3.8 |

Except for proposal number 4, the others obtained scores above 4, showing partial agreement (partial positive impact) on the established criteria. This agreement suggests that the evaluators, on average, agree that the proposals would positively affect the listed criteria.

In short, proposals 1 and 2 are exciting options with a positive character, given the suggested context. These values can also guide further studies of the proposals that obtained the highest scores.

Adopting new cultures could contribute positively to the existing process.

This study had some limitations that should be taken into account:

• How each proposal was applied was not within the scope of this work, but this information is essential for a more in-depth assessment of the impact of each suggestion.

• The origin of some proposals differs from the area where the collaborators work, which may generate some resistance.

Regarding question 5, only one contributor gave his opinion, namely:

"There is a need to adapt the processes to adopt the suggested model, which can take a considerable time to adjust all the related regulations."

## V. CONCLUSION

In conclusion, this article provides a comprehensive overview of military airworthiness certification and its relevance for aerospace products, highlighting the importance of certification activities in ensuring operational safety and human lives' preservation.

It compares the military aircraft type certification processes used in Sweden and Brazil, shedding light on good practices that could be applied to the space context. The study demonstrates the potential benefits of aligning satellite product assurance with certification activities, promoting convergence between aerospace and space processes.

The proposal for a certification approach similar to the Accredited Design Organization model in the space domain aims to enhance efficiency and credibility in the execution of the certification phases. The questionnaire results reveal partial agreement with the proposed improvements, indicating that adopting new practices could positively impact the existing process.

However, further studies and adjustments to regulations may be necessary to ensure a successful transition to the suggested model. Overall, the findings contribute to advancing spaceworthiness practices and offer valuable insights for enhancing safety standards in the rapidly evolving space industry.

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